

Tribological Challenges in Wind Turbine Technology

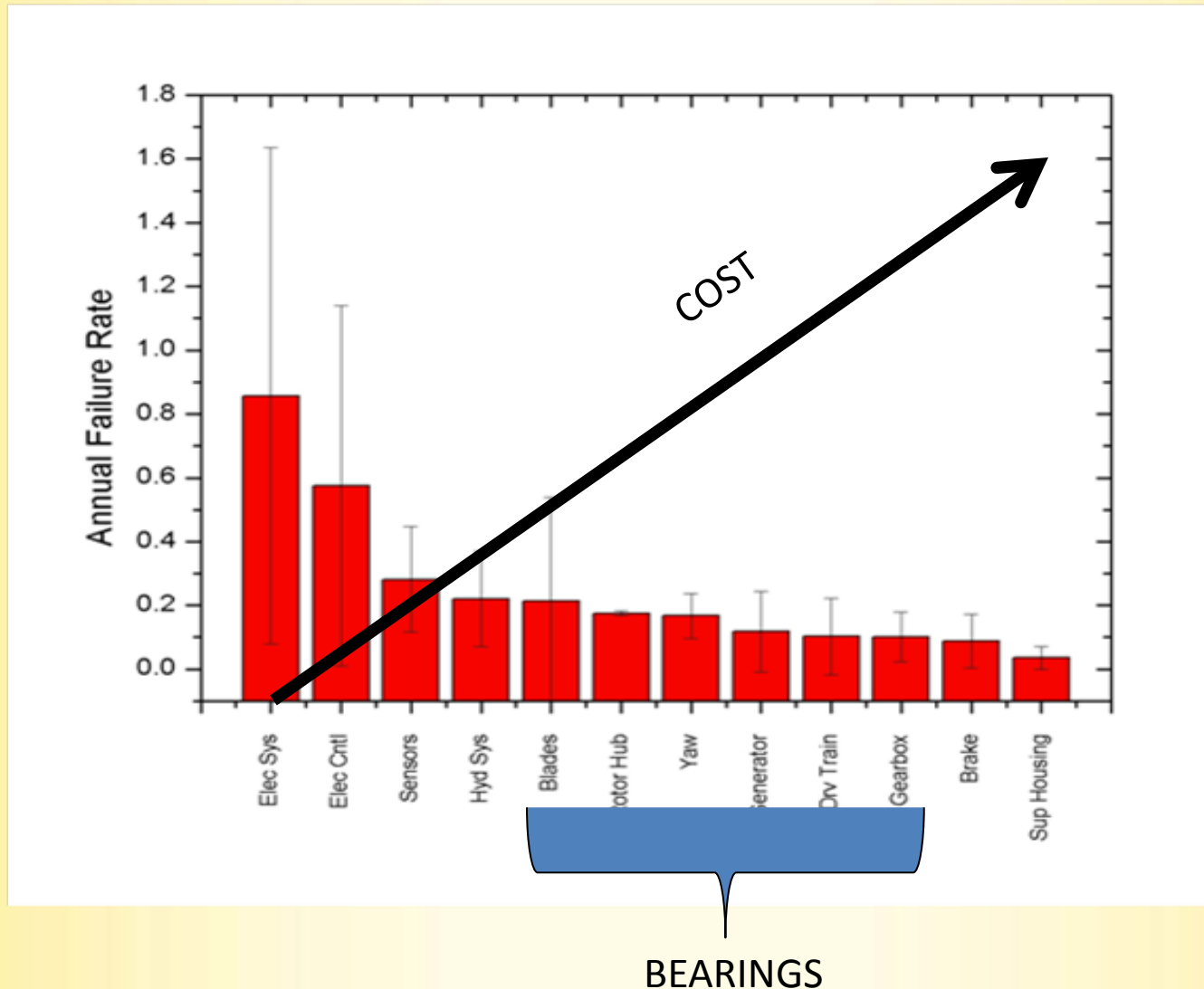
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Outline

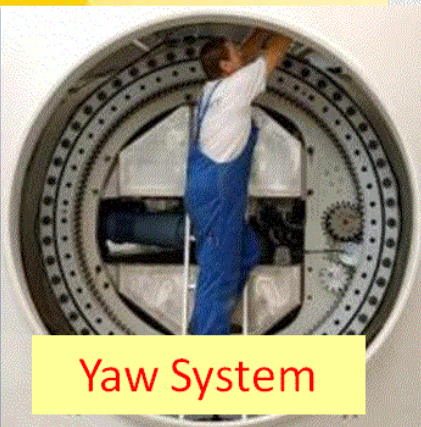
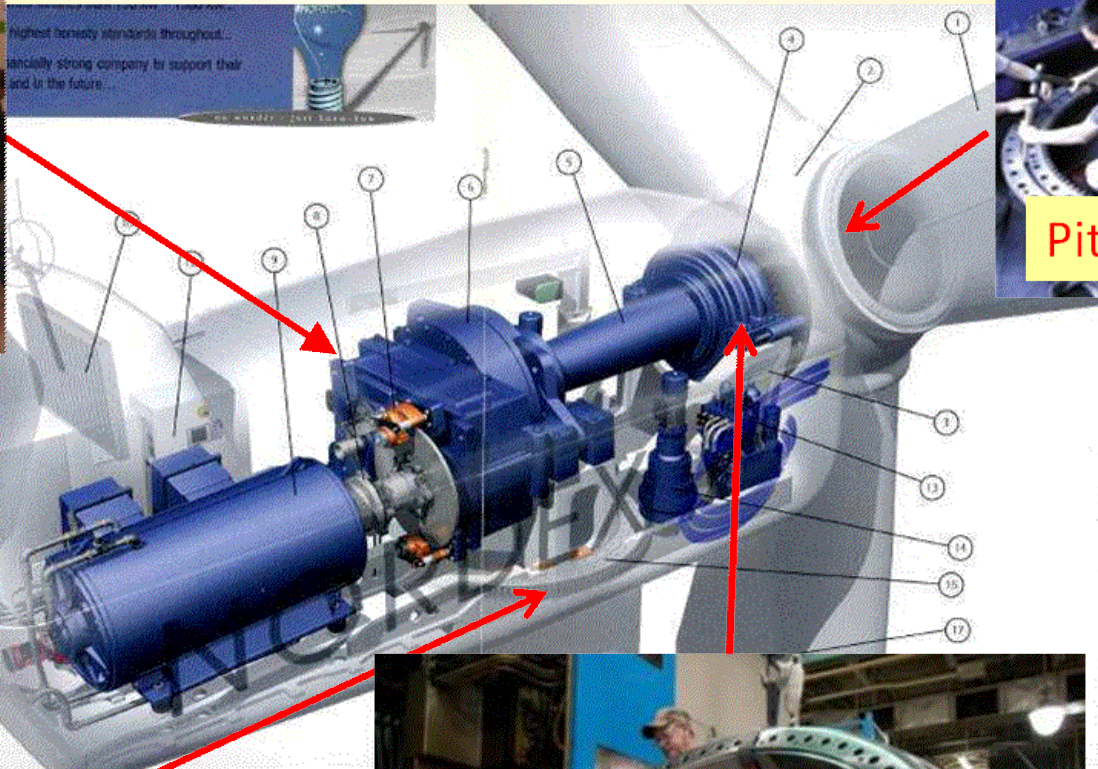
- Causes and Solutions to Life-Limiting Wear of Wind Turbine Bearings
 - Micropitting
 - Smearing
 - IrWEAs & Radial Cracking
 - Electric Arc Damage
 - Debris Damage
- Other Tribological Challenges

Component Reliability



Faulstich, S., Hahn, B., Jung, H. and Rafik, K. 2009 Suitable Failure Statistics as a Key for Improving Availability. Paper Number PO.303, Proceedings of the EWEC 2009, Marseille, France.

Wind Turbine Nacelle



Types of Rolling Element Bearings



BALL

*Generators
Yaw Bearings
Pitch Bearings*



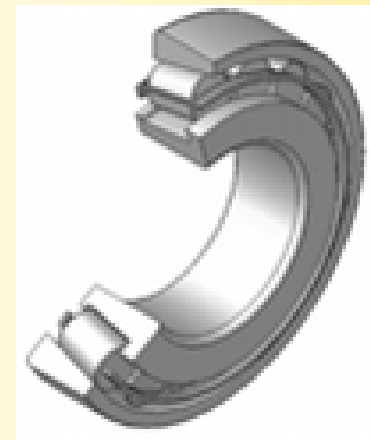
**CYLINDRICAL
ROLLER**

Gearboxes



**SPHERICAL
ROLLER**

*Main Shafts
Gearboxes*

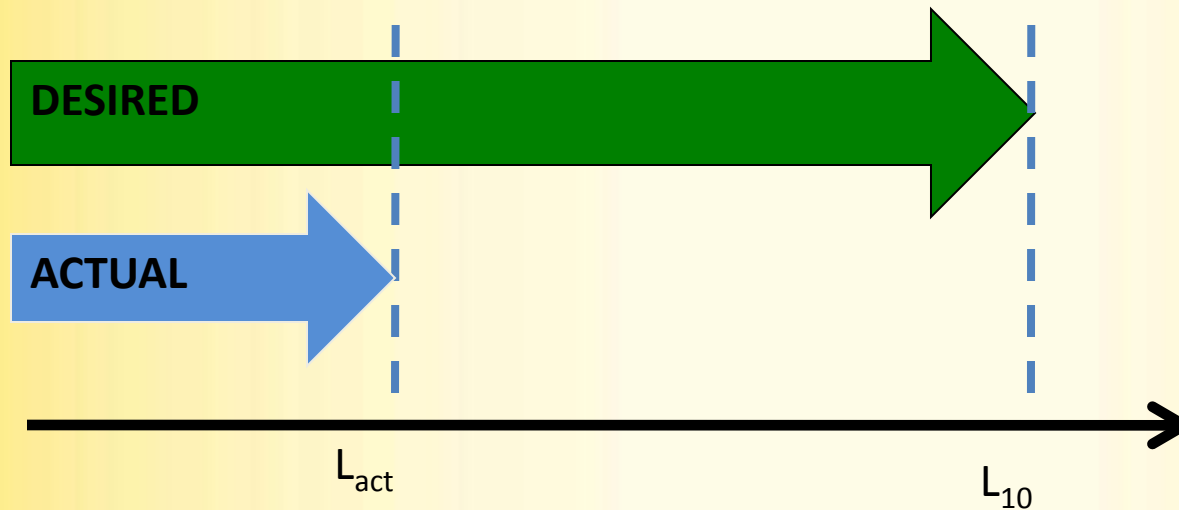


**TAPERED
ROLLER**

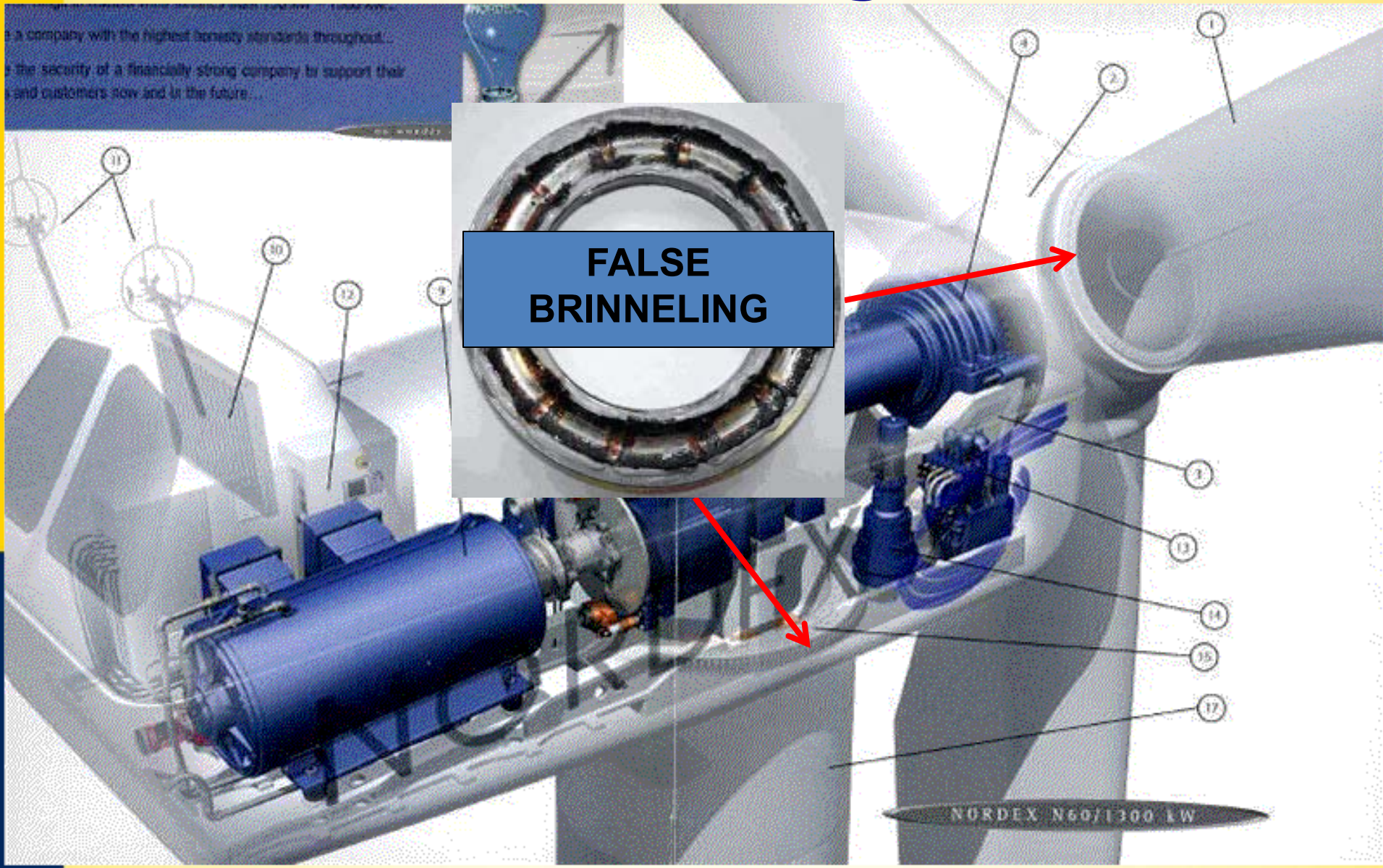
*Main Shafts
Gearboxes*

Tribological Issues

Wind Turbine Bearings Are Not Achieving Their Predicted Life



Wear Problems: Pitch and Yaw Bearings



False Brinelling – Root Cause

- Fretting can occur when bearings and gears are not rotating and are subjected to structure-borne vibrations caused by wind loads and/or small motions from the control system, termed dither.
- Under these conditions, lubricant is squeezed from between the contacts and the relative motion of the surfaces is too small for the lubricant to be replenished.
- Natural oxide films that normally protect steel surfaces are removed, permitting metal-to-metal contact and causing adhesion of surface asperities.

False Brinelling – Root Cause

- Fretting begins with an incubation period during which the wear mechanism is mild adhesion and the wear debris is magnetite (Fe_3O_4). Damage during this incubation period is referred to as false brinelling.
- If wear debris accumulates in amounts sufficient to inhibit lubricant from reaching the contact, then the wear mechanism becomes severe adhesion that breaks through the natural oxide layer and forms strong welds with the steel.
- In this situation, the wear rate increases dramatically and damage escalates to fretting corrosion.
- Relative motion breaks welded asperities and generates hematite ($\alpha\text{-Fe}_2\text{O}_3$), a fine powder that is reddish-brown in color

False Brinelling - Avoidance

- Design parameters to prevent fretting corrosion and false brinelling (Harris 2009).

$$\theta_{dither} = \frac{720^\circ b}{\pi Z \left(1 \mp D \cos \alpha / d_m \right)}$$

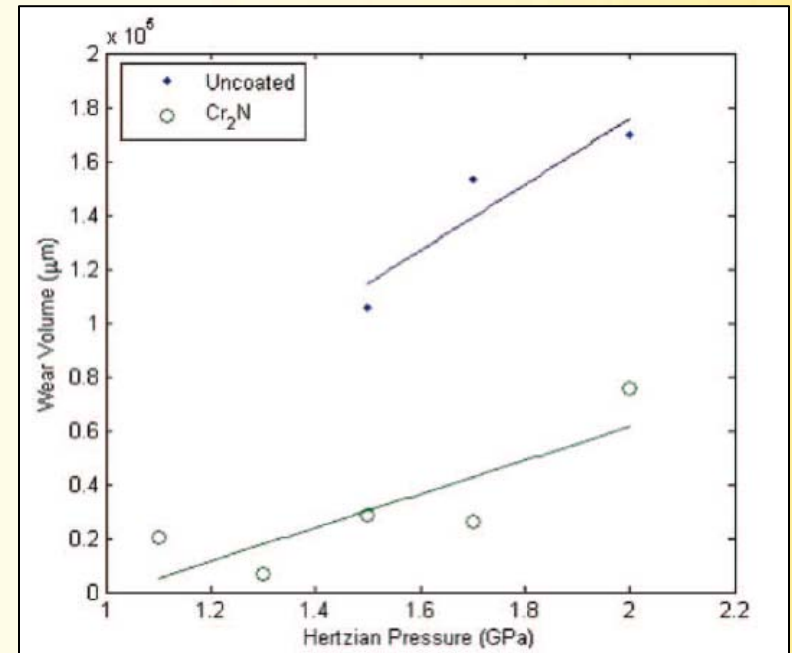
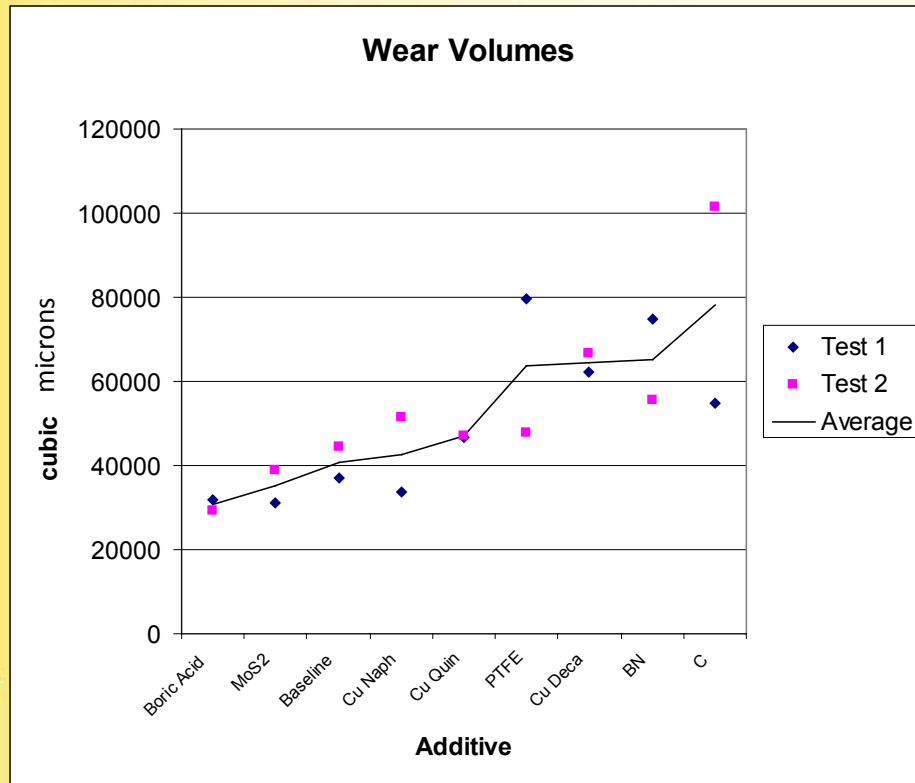
- θ_{dither} critical angle , - refers to the inner raceway, b is the Hertzian half width of contact, Z is the number of rolling elements per row, D is the rolling element diameter, α is the contact angle and d_m is the bearing pitch diameter.
- When $\theta \leq \theta_{dither}$, fretting corrosion is likely to occur.

Harris, T. A., Rumbarger, J. H., and Butterfield, C. P. 2009 Wind Turbine Design Guide DG03: Yaw and Pitch Rolling Bearing Life. Technical Report NREL/TP-500- 42362, U.S. National Renewable Energy Laboratory, Golden, CO.

False Brinelling - Avoidance

- Harris et al. (2009): avoid operating the pitch and yaw bearings under these very small oscillations and rotate the bearings as often as possible to redistribute grease to the rolling element contacts.
- Greases with adequate base oil viscosities and good anti-wear additives.
- Coat the raceways or rolling elements per Leonard et al. (2010).

False Brinelling - Avoidance



WC/aC:H : no observable wear!

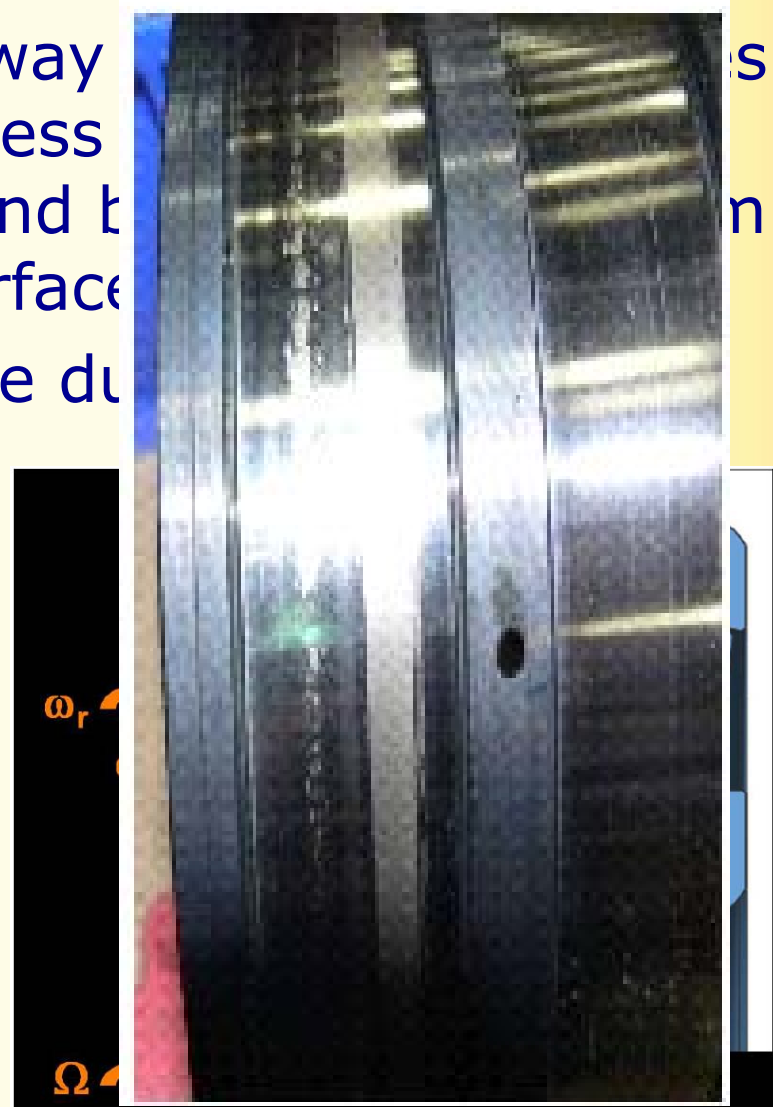
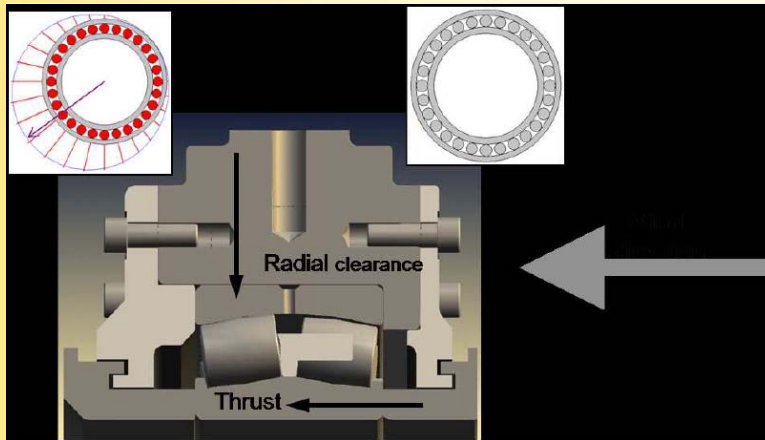
Leonard, B.D. , Sadeghi, F. , Evans, R.D. , Doll, G.L. and Shiller, P. J.(2010) 'Fretting of WC/a-C:H and Cr₂N Coatings Under Grease-Lubricated and Unlubricated Conditions', Tribology Transactions, 53: 1, 145 — 153.

Wear Problem: Main Shaft Bearing

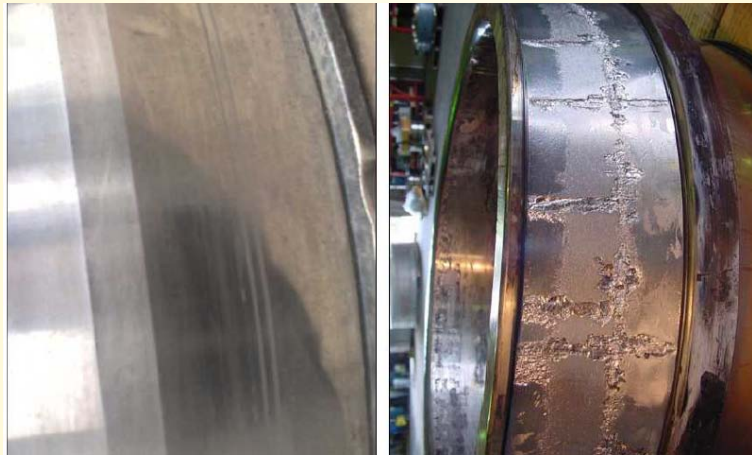


Micropitting – Root Cause

- Interaction of the raceway plus frictional shear stress contact stress values and k values closer to the surface
- Surface-initiated fatigue due to roller/raceway sliding.



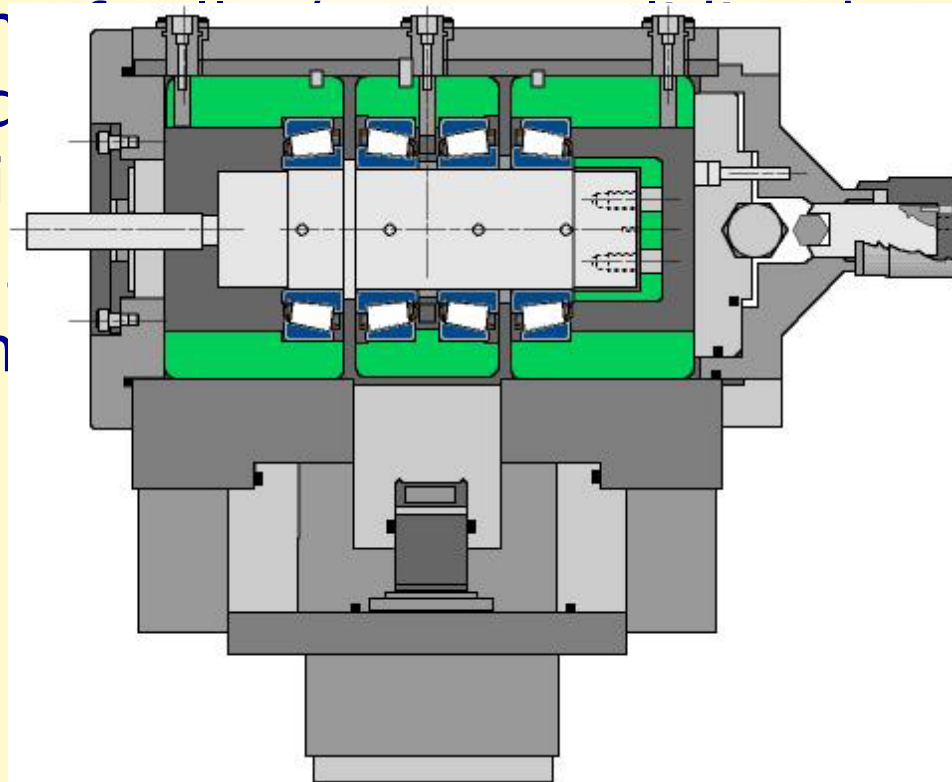
Micropitting – Leads to GSC Fatigue



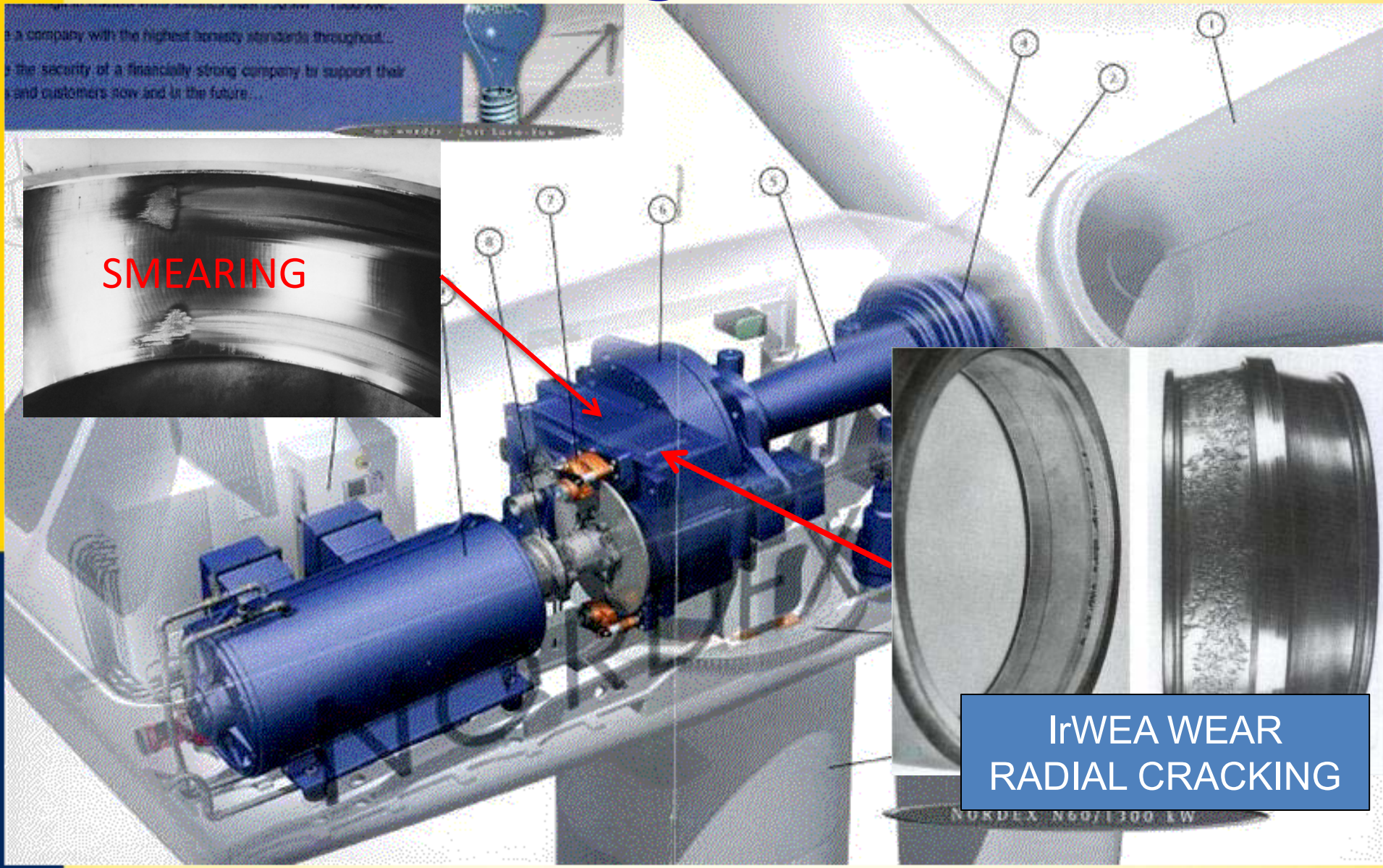
- Onset of micropitting (left): two wear tracks have emerged in the center of the raceway.
- As micropitting continues, material is worn away leading to a loss of the design contact geometry in the center and increasingly higher stress concentrations at the edges of the wear track.
- Fatigue spalls initiate at these areas of high geometric stress concentrations and propagate to the center of the raceways.
- Raceway spalling is not due to classic surface initiated or inclusion related fatigue on which the predicted bearing life is calculated.
- Raceway spalling is due to loss the designed contact geometry from micropitting wear and a concomitant increase in geometric stress concentrations at the edges of the roller/raceway contact.

Micropitting - Avoidance

- Reduction of preloaded risk of micropitting
- Coatings reduce surface polishing

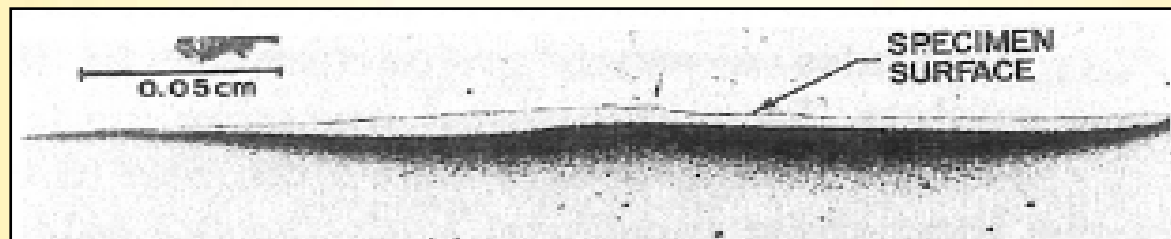


Wear Problems: Gearbox Bearings

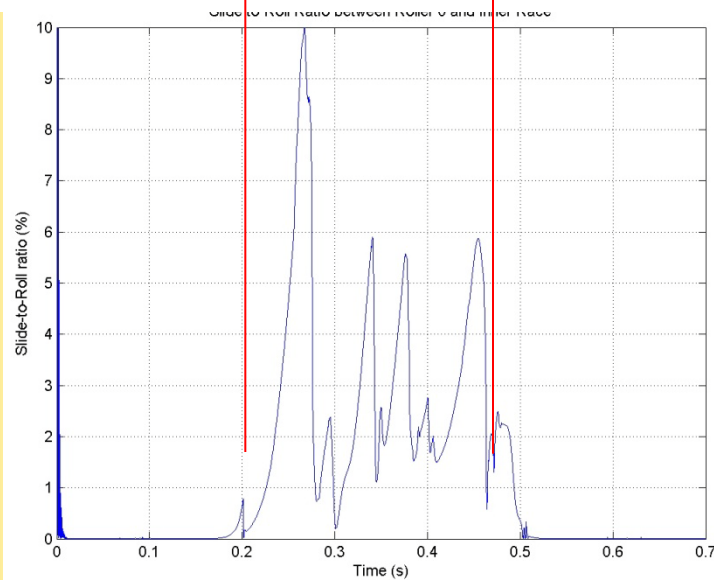
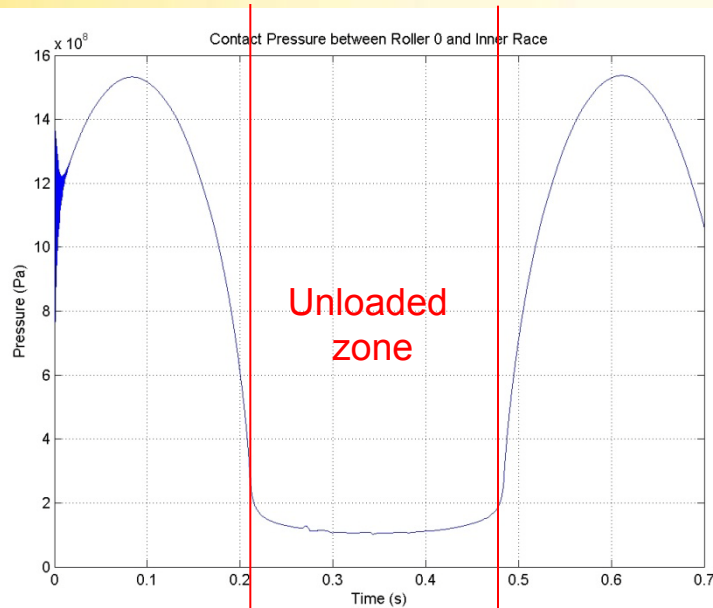


Smearing Wear – Root Cause

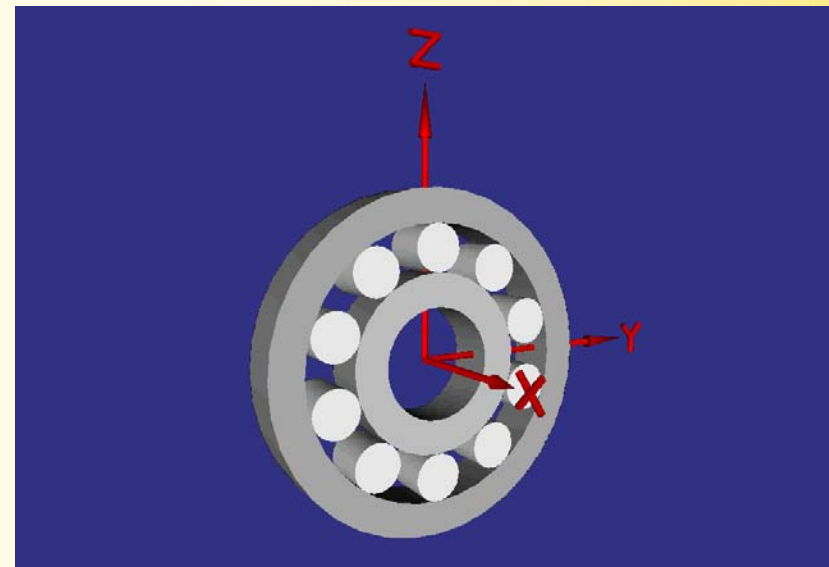
- Smearing in bearings occurs when rollers are skidding against raceways in low Λ .
- Smearing occurs when the heat from the friction between the sliding rollers and the raceways generates local temperatures in the contact zone high enough to melt the steel surfaces.
- Large-scale plasticization and localized melting generates a smeared appearance on the raceway surface.
- FeO is sometimes found in the smeared wear patch which indicates that the local temperature in the contact zone exceeded $\sim 550^\circ\text{C}$.



Roller Skidding in Gearbox CRBs

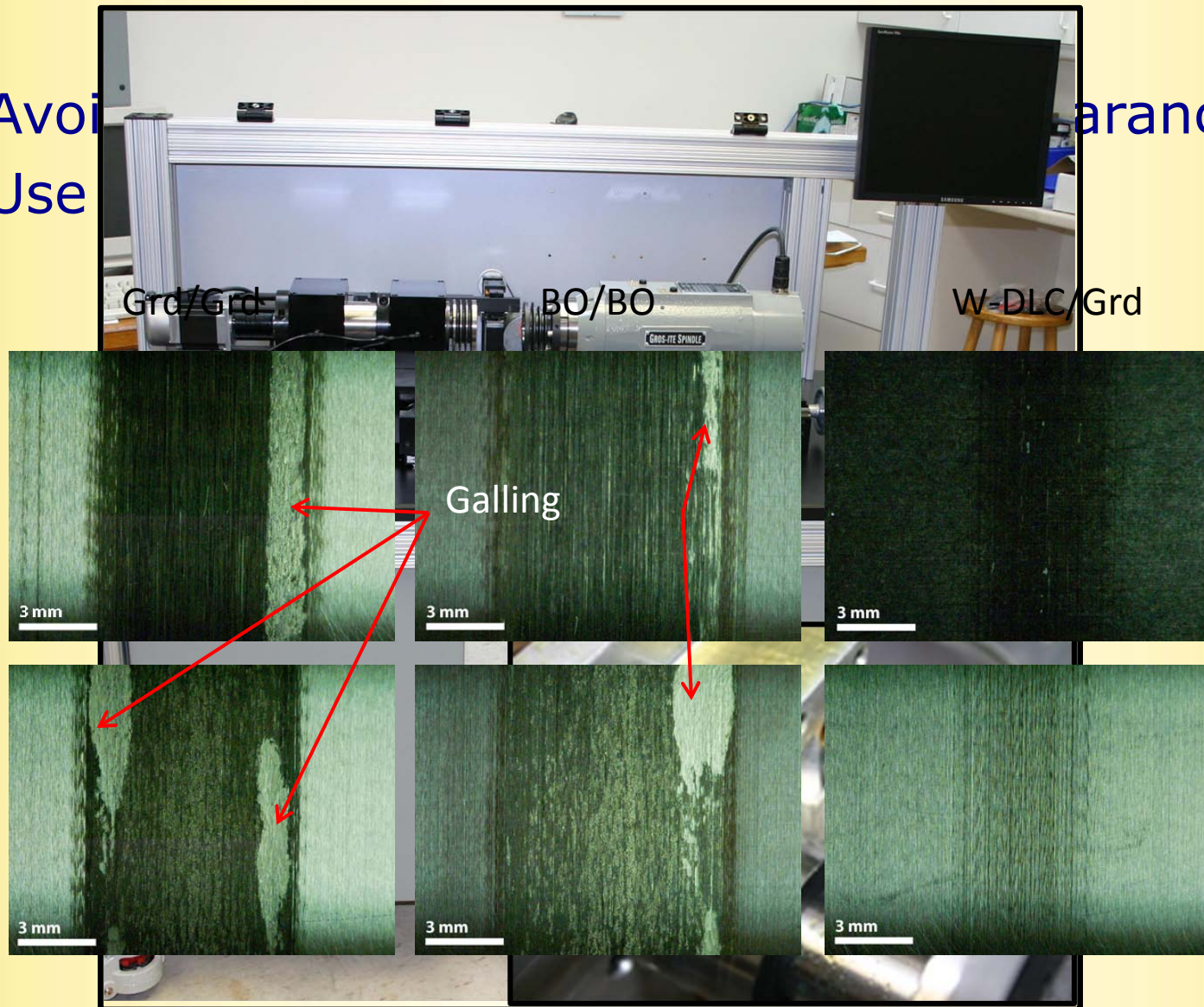


- Decreasing loads promotes more roller sliding
- Transient conditions (loads and accelerations) increases roller sliding



Smearing Wear - Avoidance

- Avoidance of Smearing Wear.
- Use of appropriate materials.

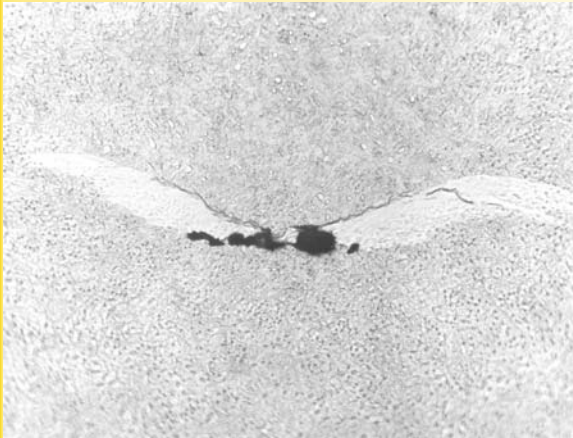


Radial Cracking & Wear from IrWEA

- H Embrittlement
 - Heat Treatment
 - Decomposition of Lubricant
 - Electrostatic Discharge
- Mechanical Causes
 - Transient Loads & Skidding Rollers
 - Adiabatic Shear: Dynamic loads associated with the pressure spike in EHL contacts



Radial Cracking & Wear from IrWEA



“Normal” Butterflies at Inclusions



“Abnormal” Butterflies (IrWEAs) at Inclusions



Crack Network

OEM Observations

- Extremely high content of butterflies in each cross section.
- Typically evenly distributed around the bearing widely branched white etching sub-surface alterations growing parallel to the surface, perpendicular to the surface or in variable directions.
- Associated with the use of oil lubrication (mineral, PAO and PAG).
- Black Oxide helps
- Not observed in case-carburized rings
- Inner rings usually, rarely outer rings

Mechanical Issues from Transient Effects

Troubleshooting Wind Gearbox Problems

By Jarek Rosinski and David Smurthwaite

In order to prevent in-service failures in wind turbine gearboxes, an in-depth understanding of how and why they occur is required.

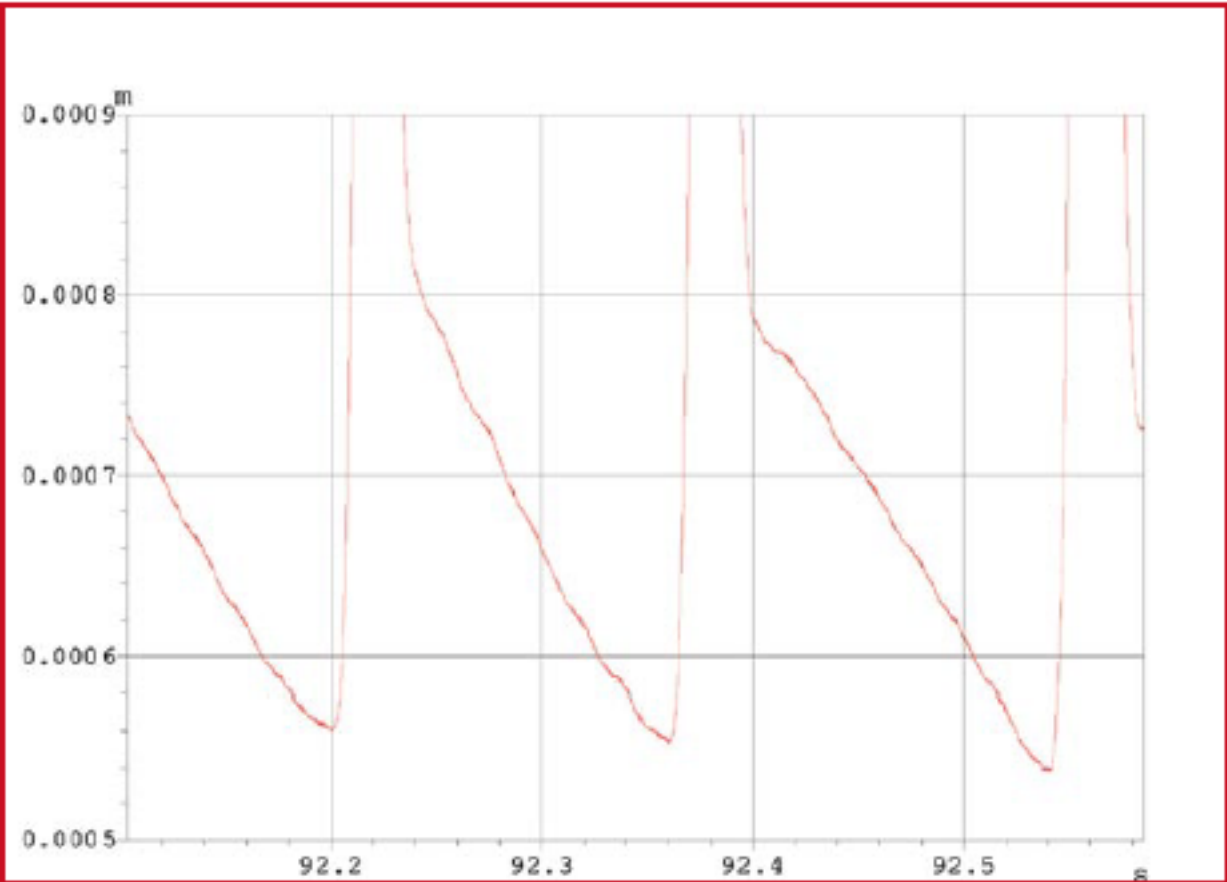
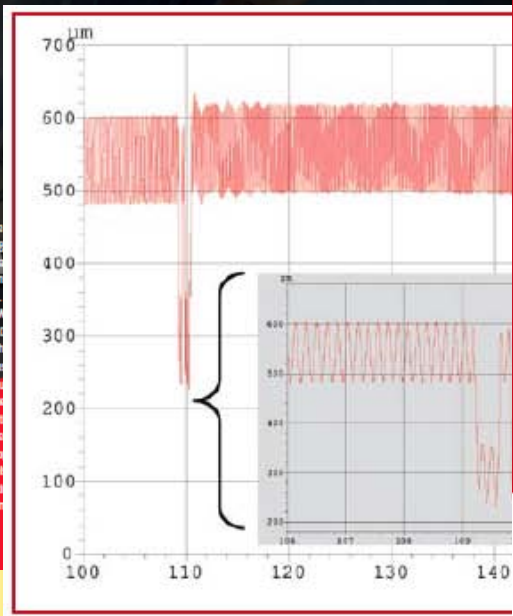
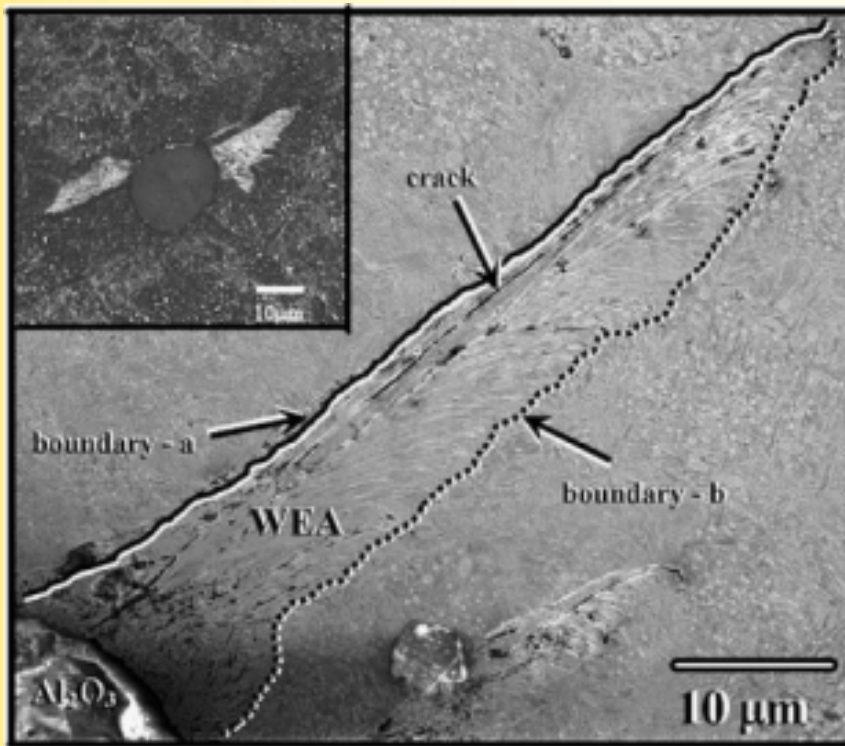


Fig. 16: Detail of bearing axial displacement from test 6, showing over 200µm skew.

Rosinski J. and Smurthwaite D. 2010 Troubleshooting Wind Gearbox Problems. Gear Solutions, **8**, 22-33.

IrWEAs from Very High Shear Stresses in 52100



- Voids & microcrack initiate at inclusion/steel interface
- Microcracks agglomerate & propagate along ferrite wings

*A. Grabulov, R. Petrov, & H.W. Zandbergen, Intl. J. Fatigue, 32 (2010), pp. 576-583.

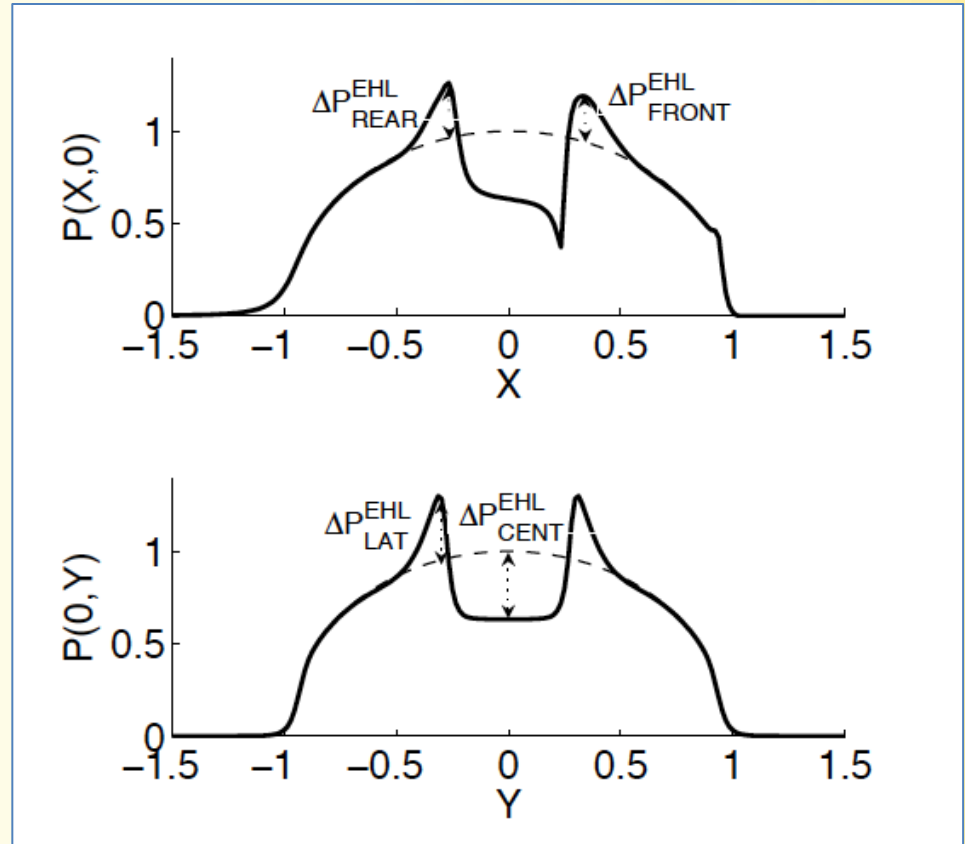
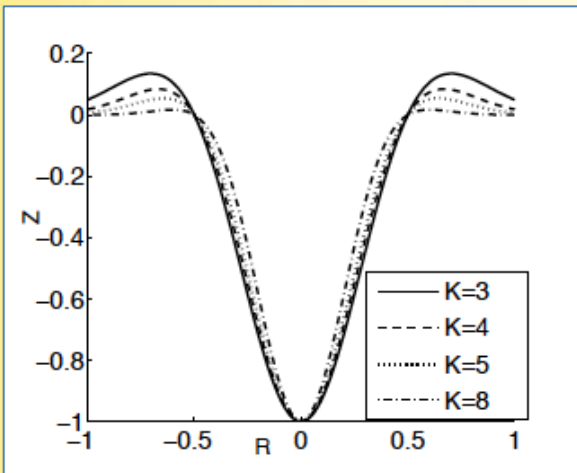
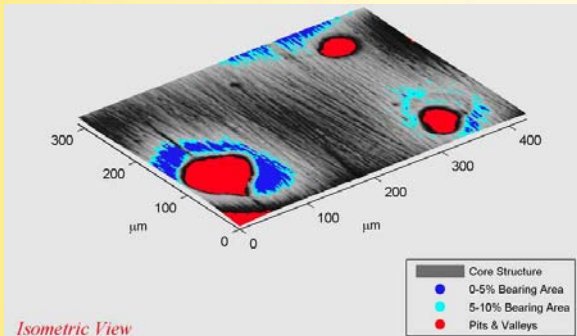
Mechanisms: Correlations with Observations

	IrWEAs on Inner Ring Only	Fe ₃ O ₄ reduces IrWEAs	Smearing Wear
H from Heat Treatment	-	-	-
H from Lube/Additives	-	-	-
H from Electrostatics	-	+	-
Transient Loads/Skidding Rollers	+	+	+
Adiabatic Shear	-	+	-

Avoidance of Radial Cracking & Wear from IrWEAs

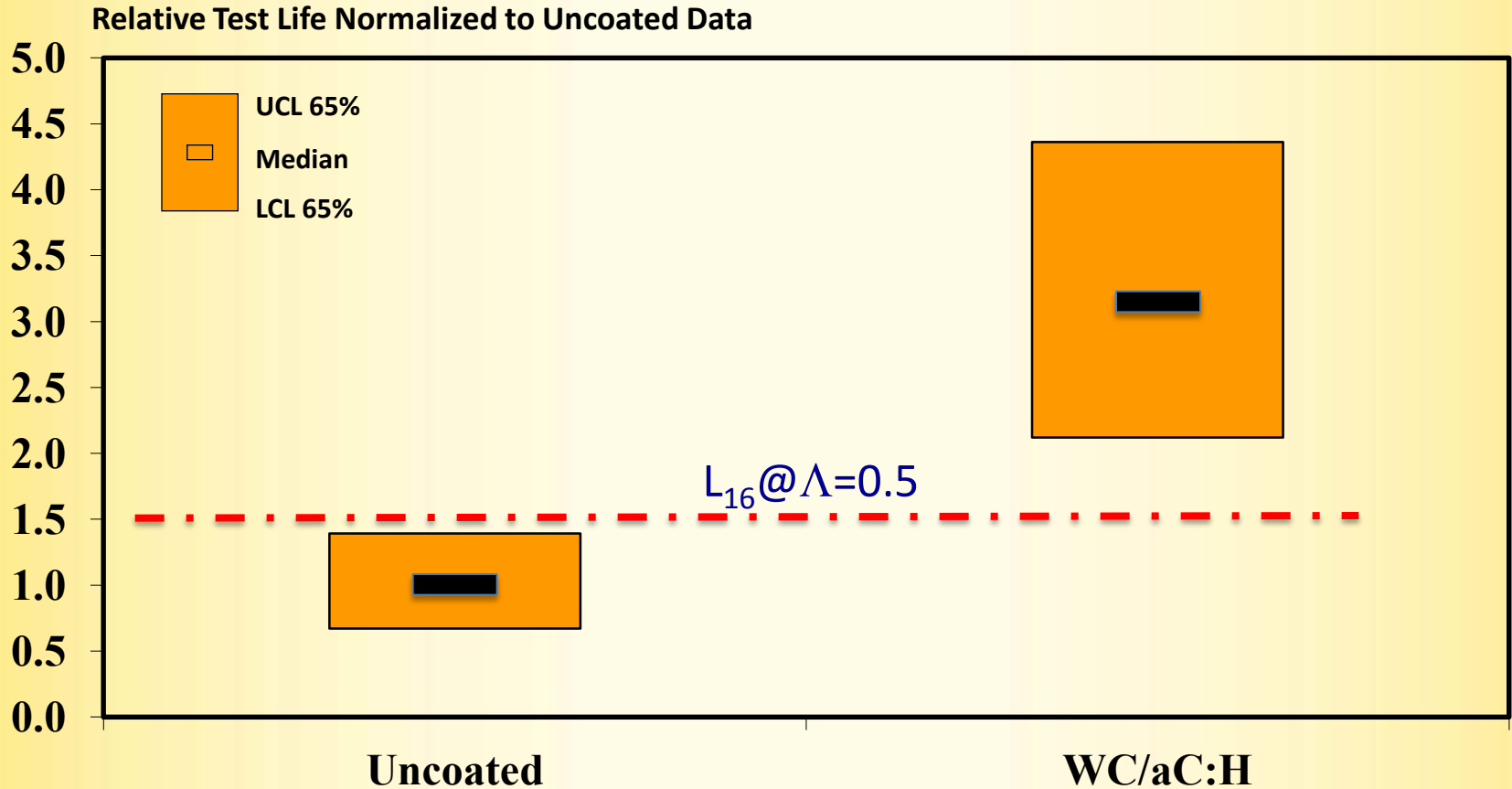
- Field data suggest that black oxide on rings and rollers reduce occurrence of radial cracking and IrWEAs.
 - When Fe_3O_4 wears away, very smooth surfaces are left behind. Higher Δ , lower shear stresses from skidding rollers.
- Field data suggest that case carburized rings from ultra clean steel have reduced risk of radial cracking and IrWEAs.
 - Higher compressive surface stresses inhibit crack propagation
 - Fewer inclusions, lower IrWEAs
- Methods to reduce shear stress
 - Pre-loaded TRBs have less roller skewing than CRBs
 - Coatings (WC/aC:H) on rollers reduce shear stress from skidding rollers.

Debris Damage & Fatigue Life



Nans BIBOULET Thesis, I.N.S.A. de Lyon INFLUENCE OF INDENTATIONS ON ROLLING BEARING LIFE

Debris Damage & Fatigue Life

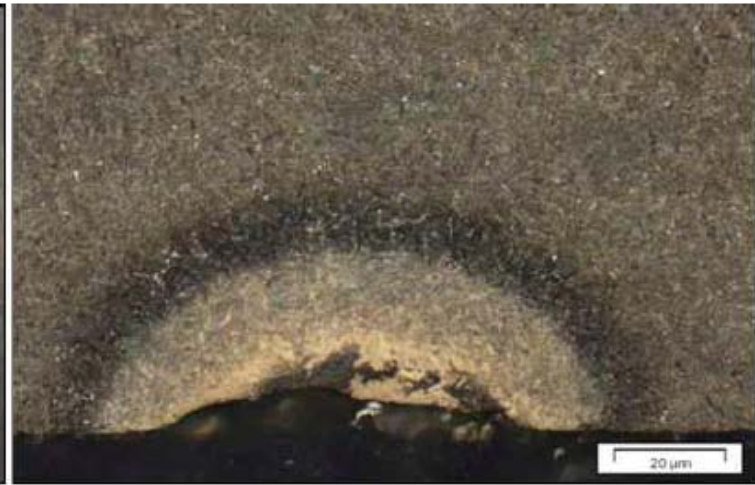


Electric Arc Damage in Generator Bearings

Electrical current damage on the outer raceway of a bearing: (a) Photograph of the body raceway surface; and (b) Cross section of a pit, mounted, polished, nital etched and magnified 600x showing the removed material, rehardened and retempered layers.



(a)



(b)

Kotzalas, M.V. and Doll, G.L. (2010), Phil. Trans. R. Soc. A vol. 368 no. 1929 4829-4850.

Electric Arc Damage

- Root Cause:
 - High-frequency currents induced in the shaft can pass through the rolling elements causing extreme local heat and small burnt pits in the bearing raceways.
- Possible Solutions:
 - Ceramic balls for rolling elements in the bearing, (hybrid bearings). But has not always worked.
 - Srinidhi et al. (2009) Retainer material – no effect, but there was a significant difference between oil and grease.
 - Electrical insulating coatings (Al_2O_3) on rings.
 - Dry Oils with high dielectric strengths.

Srinidhi, S., Tiwari, M., Burra, R., Gowda, H., and Siemers, P. 2009 Bearing Wear due to Mechanical Stresses and Electrical Currents. IJTC2009-15255 Proceedings of the ASME/STLE International Joint Tribology Congress, Memphis, TN.

Other Tribological Challenges

- Gear Scuffing & Micropitting
 - Same surface solutions as roller bearings
- Debris Damage to Gears
 - Coatings (WC/aC:H) should function similarly to roller bearings
- Seal Life
 - A 20 year lip seal?
- Common lubricants
 - Mainshaft, Pitch, & Yaw systems
 - Operation vs. Shipping & Storage
 - Generators may need to use oils

Summary

- Some wind turbine bearings are not achieving their desired operational lives because of life limiting wear modes.
- Micropitting & Smearing caused by large amounts of roller/raceway sliding in low Δ .
- Root cause of Radial Cracking & Wear from IrWEAs is controversial, but probably mechanical.
- Micropitting, Smearing, and False Brinelling problems can be solved with durable WC/aC:H coatings on rollers.
- Cleaner steels, higher compressive stresses on raceways, increased Δ , and less roller skidding can reduce IrWEA wear and radial cracking if mechanical origin.
- Less electric arc damage in oils than greases.
- Solutions to Micropitting and Scuffing in gears same as roller bearings.
- WC/aC:H coatings on rollers provide bearings with high tolerance of debris damage.
- Problems without current solutions: seal life and common nacelle lubricant.

Acknowledgements

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- Les Miller - Kaydon
- T. Harris, T. Talian, & F. Sadeghi

Questions?

